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GPS and Its Application in Navigation System Test Flights

1. Introduction

With the rapid development of science and technology, the global positioning system appeared in April, 1993, when the United States sent the last satellite into orbit and declared that the GPS constellation of 24 satellites was finally deployed. This system, gradually perfected and mature, has been widely applied in aviation, aerospace, sea voyage, geodesy, land navigation as well as in various military and civil projects. Featuring global coverage, all-weather operation, high cost-efficiency of user equipment and capabilities of providing high precision data, including location, velocity and time, GPS and differential GPS were successfully applied in the navigation system test flights as location and velocity references.

2. The GPS User System

To meet the requirements of the navigation system test flights, a Pathfinder GPS System was imported from the Trimble Company in the United States.

2.1 The Pathfinder GPS

The Pathfinder GPS System is a new generation 6-channel standard positioning setup (SPS) developed by the U.S. Trimble Company, which, with C/A code, can provide location, velocity and time information on a global basis 24 hours in all weather. The Pathfinder series products include four models: (1) Polycorder; (2) MC-V; (3) Basic and (4) Basic Plus. The first two receivers are identical in shape, with a combination of display control and data recorder in different shapes, while the MC-V possesses more

powerful functions. The fourth model, the Basic Plus, combining the receiver, display control, battery and recorder as a whole, is characterized by small volume and light weight. Also, it contains an internal antenna and is available for connecting to an outer antenna, convenient for carrying. The data recorder can store data; if it records data once a second, it can record more than 2.5 hours, which is extremely practical at present when GPS has no data bus interface. The four GPS models can all be used either as reference stations or long-range stations depending on the goal and the equipment condition before being used. If two receivers operate simultaneously, they can be used for differentiation.

2.1.1 Major Technical Indexes

Location Precision: spherical error probability (SEP) 25m; selected availability (SA) 100m(2dRMS) while effective; differentiation less than 5m after correction.

Velocity Precision: 0.02m/s in stable condition and without considering SA.

Response Time: less than 2min.

Time Service: pulse-drop time synchronized with international coordination time within 1 microsecond, with a pulse width 1 microsecond.

Dynamic Adaptability: velocity 400m/s; acceleration 4g; vibration 2g/s(20m/sec^3).

2.1.2 Reference Station

A reference station, located where an accurate geodetic survey has been done, consists of antenna, receiver and PC computer and carries special cables and code keys. As long as

the cables are correctly connected and the software is put into the PC computer, the receiver can be switched on and begin to record data soon after it receives a satellite signal. It can record data 24 hours a day and defines one data file every hour, and it can also provide real-time differentiation (if there is a data link) and post-differentiation within 500km in all directions. Through real-time differentiation, the corrected data are broadcast to long-range station users in the form of RTCM SC-104 as stipulated by the Radio Technology Committee.

The reference station receives and records the sidereal and satellite viability, 8 visible satellites and the pseudo range of each satellite, Doppler velocity, signal-noise ratio and other data. For the post-differentiation, data can be recorded every 3-5 seconds, usually every 5 seconds.

The screen can also be used to set up and control various switches, and display various information including satellite status, various DOP values, recorded files, starting and ending time, satellite code phase, Doppler velocity and signal-noise ratio.

2.1.3 The Long-Range Station

Basically, a long-range station is composed of four parts: antenna, receiver, data recorder and power supply. The entire system is compact, powerful and has storage capability. It can preset various states and recording files before flight and automatically record data in flight. It can also set air route way stations, display flight range and flight time and estimate navigation parameters such as arrival time, flight declination distance, flight declination angle, etc. When the flight is over, these data are loaded into the PC computer, either for single device use or for differentiation.

2.1.4 Post-Differentiation Processing

The Pathfinder system has a complete set of data processing software, including reference station software, long-range station software and post-differentiation software.

There are two modes for post-differentiation processing. One of them is space measurement, in which the raw data of each satellite in the star calendar are used to determine the difference between the pseudo range and actual range of each satellite. These pseudo range errors are used by the Pathfinder to correct the location of the long-range station. This differential correction mode has a higher success rate but slower calculation speed. The other post-differentiation processing mode is space calculation, in which the reference station and long-range station employ the same four satellites at the same time to correct the location of the long-range station at the same instant by using the latitude, longitude and altitude errors, that is, the difference between the Pathfinder-calculated location of the reference station and its actual location.

For satisfactory differentiation, the elevation threshold value of the long-range station should be several degrees higher than that of the reference station.

Data processing involves many data files. For instance, RAW designates primitive files, SSF standard files, COR differential files, ASC the ASCII code files as well as statistical files, velocity files and some intermediate conversion files.

2.2 Ground Differentiation Tests

Reference stations and long-range stations were established at the coordinate points where accurate geodetic survey had been done with Pathfinder Basic Plus GPS as the long-range stations. All together eight ground differentiation tests were conducted,

during which more than 14,000 data points were derived. These data are shown in Table 1. Based on the data in Table 1, the test results of GPS ground differential correction and non-differentiation were calculated.

Non-differentiation:	CEP=31.42m
	SEP=55.98m
	ΔV=0.362m/s(RMS)
	ΔH=55.82m(RMS)
Differential Correction:	CEP=2.76m
	SEP=4.40m
	ΔH=4.13m(RMS)

3. Application of GPS in Navigation System Test Flights

3.1 Application of Single GPS in Determining Positioning Precision of an Inertial Guidance System

As the inertial guidance system has the inherent property of accumulating errors with time, the technical indexes set for intermediate precision military-oriented inertial guidance are: location precision 0.8n mile/h and velocity precision 1m/s. Even if SA is in effect, the location error made by a single GPS is only 100m and velocity error is 0.02m/s. Therefore, the single GPS is a simple and effective way to discriminate the location and velocity precision of the inertial guidance system. Fig. 1 shows the radial location error curves of the American civil-oriented inertial guidance system LTN-72 mounted on a call aircraft in test flight compared with GPS. Fig. 2 displays the typical location error curves of a domestic inertial guidance system mounted on a fighter compared with GPS.

The Pathfinder GPS was used on transportation planes, bombers and fighter planes as reference equipment. At present, its flight status is: altitude 15,000m, M number 1.55, ground velocity 1700km/h, true velocity 1600km/h, overload 4.8g. The

GPS can operate in a normal way in the process of acceleration and at the above-mentioned maximum velocity without missing any satellite. It underwent various maneuvers such as a dive and pullup, left and right large-slope circling, left and right horizontal rolls, etc. During small slope flight, it basically does not miss satellites, while in large slope flight, it had to replace satellites many times; occasionally two-dimensional positioning was executed and in individual cases, it might miss satellites for over 10 seconds. This mainly depends on the distribution of satellites and the aircraft fuselage condition.

3.2 Application of Differential GPS in Determining Precision of Combined Navigation System

The inertial/satellite combined navigation system is a nearly ideal air-borne navigation system which is likely to be widely applied soon. This system, combining extremely high precision satellite long-term positioning and velocity finding precision with the stable inertial guidance high bandwidth short-term positioning and velocity finding, can continuously provide real-time and high precision location and velocity information, and realize testing and compensation of gyro drift. Obviously, it will be regarded as an excellent navigation system to be employed in various types of aircraft.

From 1993 to 1994, research-oriented test flights were conducted for two types of combined navigation systems: one is the platform inertial guidance/satellite combined navigation system, while the other is the strapdown inertial guidance/satellite combined navigation system. The major precision indexes expected were: location precision 300-500m(CEP) and velocity precision 0.5-2m/s(RMS).

To meet the technical indexes from the above two combined navigation systems, the location and velocity precision of the two systems was measured with differential GPS as reference equipment. A Transportation 7 plane was selected for the test

flight. The entire test arrangement is shown in Fig. 3. The data output by the combined navigation systems were sent to the air-borne collection and recording system and recorded by a magnetic tape unit, while the long-range station carried its own storage for data recording. The time synchronization of the two was realized through the time service, given by the time service GPS to the time code generator.

During the flights, the long-range stations and reference stations started recording simultaneously. When the flight was over, data from the long-range stations were put into the PC computer, where they underwent post-differentiation with the post-differention data processing software and then was saved on a disk. These data, together with air-borne data, were subject to error computation at the ground computation station or subject to error computation and plotting in PC computer.

Through a comparison between the data from the combined navigation system and data from the differential GPS in the same instant, the typical error curves of the platform inertial guidance/satellite navigation system and those of the strapdown inertial guidance/satellite navigation system were plotted as shown respectively in Fig. 4 and Fig. 5. The final error results of the two systems were derived from error statistical computations: location error 129m(CEP) and velocity error in stable flat flight 0.5m/s(RMS) for the platform inertial guidance/satellite navigation system; location error 229m(CEP) and velocity error in stable flat flight 1.3m/s(RMS) for the strapdown inertial guidance/satellite navigation system. The test flight results and plotted curves indicate that it is satisfactory to use differential GPS as reference to discriminate combined navigation systems.

Owing to its advantages including high precision, high reliability, low cost and convenient operation, GPS will have

even wider applications in aircraft performance and air-borne equipment test flights.

4. Application of GPS in Attitude Determination

Since the advent of GPS and especially when the differential carrier wave phase tracking technology was developed at the end of the eighties, institutions of higher education in some foreign countries enthusiastically started working on the application of GPS in aircraft attitude determination. They followed the principle that radio interference at two or more receiving antennas could be used to accurately determine a slight displacement of the base line connecting these antennas. The relative locations of antennas installed in different places of aircraft could be measured in flight through a GPS interferometer and then, the aircraft attitude could be deduced from these locations. The foundation of such measurements was to raise the positioning precision up to centimeters or even a higher order of magnitude. Only in this way, could the angular displacement of the connecting line between the same base-line and two antennas phase centers relative to its reference location be compared. For a base line 30 meters long, the possible precision is 1 milliradian (3.4 arc-minutes). This precision can increase to 0.1 milliradian if accurate control of multipath effect, antenna type and location can be realized. In a recent test flight made by Stanford University, a 3-meter long receiver base line was adopted, which resulted in an attitude precision better than 0.1^0. In addition, GPS can also be used for course determination without being affected by the magnetic field. At present, GPS attitude determination technology remains at the transition stage from laboratory development to engineering experimentation. Once this technology succeeds, GPS will possess an additional function and provide a high precision testing means for attitude reference in test flights.

Table 1. GPS Ground Differentiation and Non-differentiation Test Data

(1) 序号	(2) 试验日期	(4) 远程站差分修正后 (m) (3) 数据点数						(6) 远程站不差分 (m, m/s) (5) 数据点数										
		(3) 数据点数	ΔN	ΔE	ΔH	ΔR_H	ΔR_s	(5) 数据点数	ΔN	ΔE	ΔH	ΔR_H	ΔR_s	ΔV_E	ΔV_N	ΔV_Z	ΔV_s	ΔV_H
1	1993.10.11	1012	2.22	2.37	4.71	3.25	5.72	1548	16.65	18.73	40.00	25.06	47.21	0.20	0.21	0.46	0.54	0.28
2	1993.10.12	1183	3.88	1.44	2.35	4.13	4.76	2762	30.39	19.70	57.18	36.22	67.69	0.17	0.26	0.64	0.71	0.31
3	1993.10.17	1208	2.81	1.78	5.40	3.32	6.34	2746	25.84	18.05	54.68	31.52	63.11	0.16	0.28	0.46	0.56	0.32
4	1993.10.20	3451	2.04	1.87	3.88	2.76	4.76	3611	21.13	25.04	60.84	33.06	69.24	0.28	0.21	0.52	0.62	0.35
5	1993.10.23	4091	2.68	2.02	5.52	3.35	6.46	4861	23.98	17.34	49.55	29.59	57.71	0.17	0.21	0.48	0.55	0.27
6	1993.11.2	253	2.35	1.05	3.74	2.58	4.54	254	24.42	18.22	51.23	30.47	59.60	0.13	0.20	0.46	0.52	0.23
7	1993.11.7	1234	2.59	2.56	3.59	3.64	5.11	1234	35.43	41.02	87.57	54.20	102.99	0.27	0.29	0.58	0.70	0.40
8	1993.11.9	1827	1.63	2.93	2.67	3.35	4.28	1842	25.61	45.24	24.78	51.98	57.98	0.50	0.33	0.25	0.65	0.60
总计 (7)		14259	RMS		4.13	3.33	5.30	18858	RMS		55.82	37.86	64.45	RMS			0.61	0.36

Key: (1) Serial number; (2) Test date; (3) Number of data points; (4) Long-range station post-differential correction; (5) Number of data points; (6) Long-range station in the absence of differentiation; (7) Total

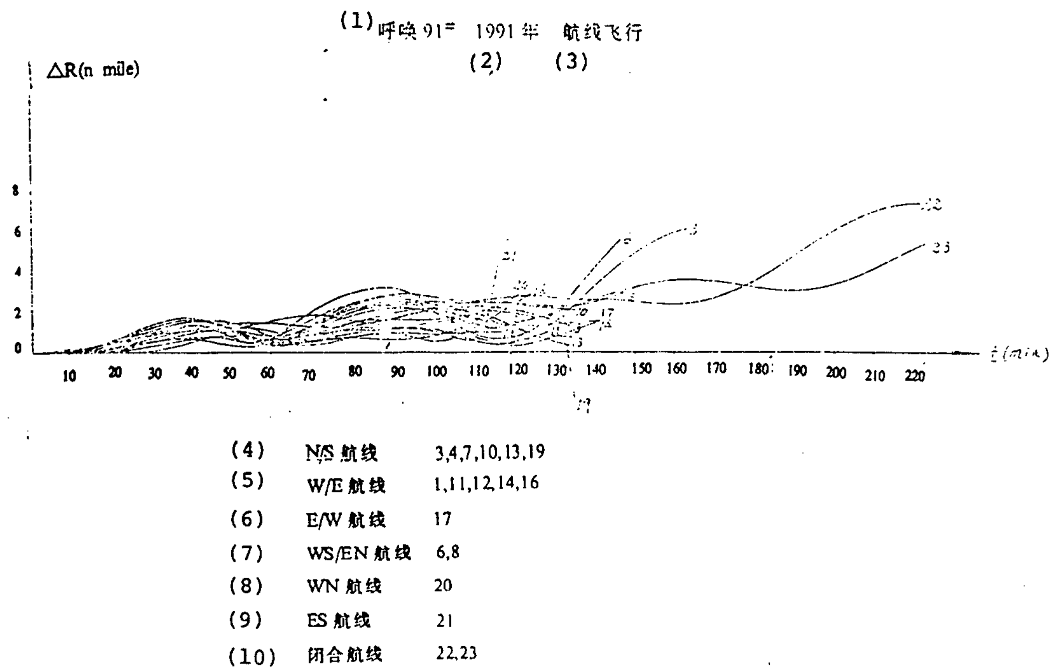

Fig. 1. Radial Location Error Curves of LTN-72-R Inertial Guidance System in Different Sorties

Key: (1) Call 91#; (2) 1991; (3) Air line flight; (4) N/S air line; (5) W/E air line; (6) E/W air line; (7) WS/EN air line (8) WN air line; (9) ES air line; (10) Closed air line

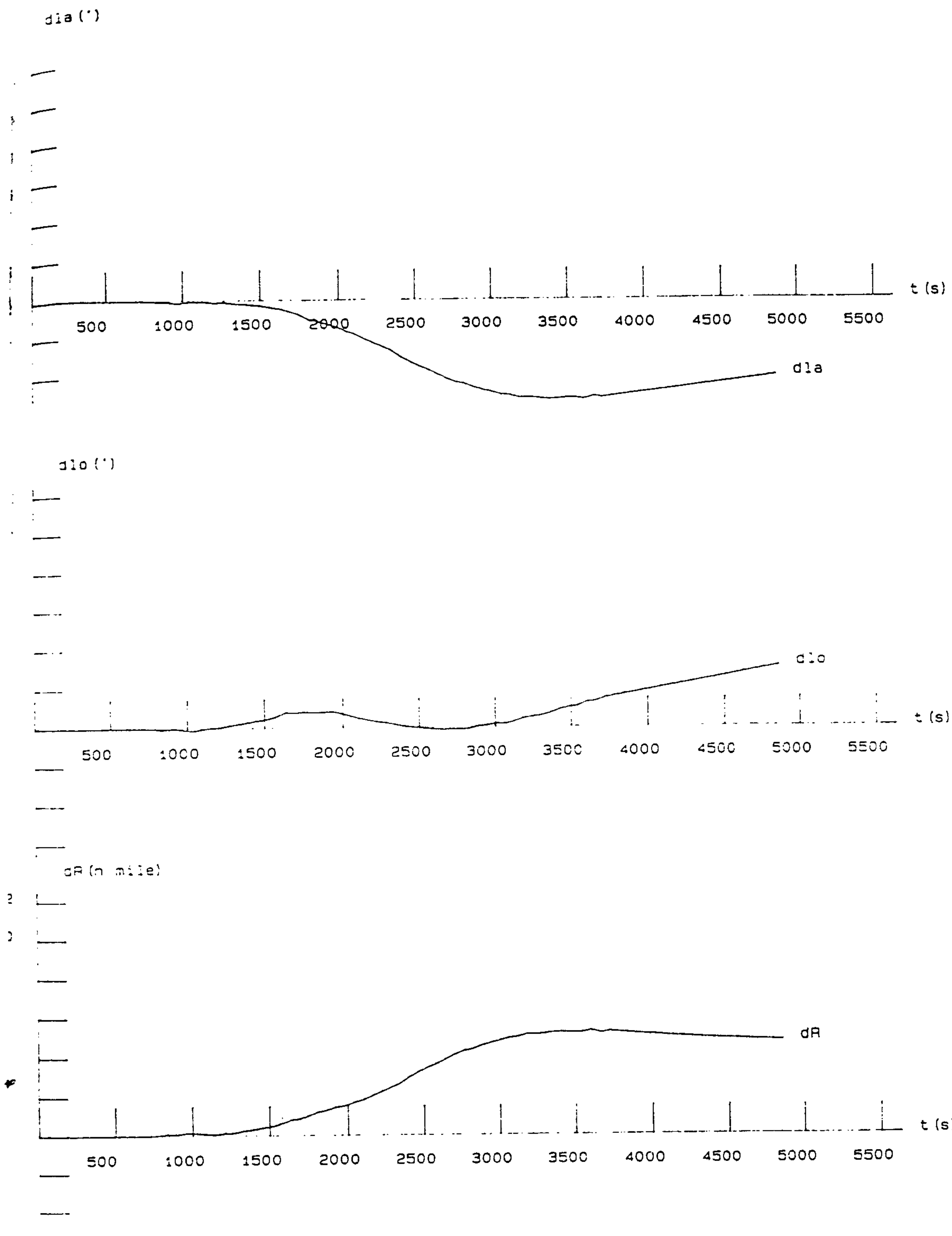

Fig. 2. Location Error Curve of a Domestic Inertial Guidance System on No. 17 Sortie

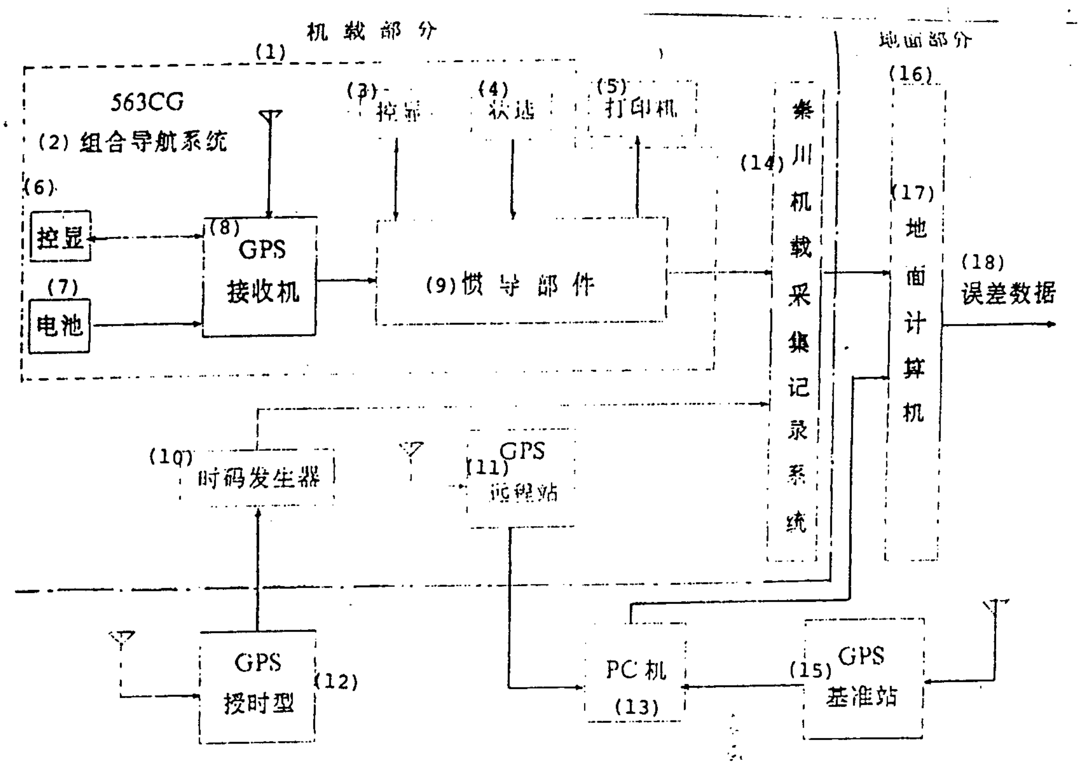

Fig. 3 Block Diagram of Test Instruments

Key: (1) Air-borne instruments; (2) 563CG combined navigation system; (3) Display control; (4) State selection; (5) Printer; (6) Display control; (7) Battery; (8) GPS receiver; (9) Inertial guidance parts; (10) Time code generator; (11) GPS long-range station; (12) Time service GPS; (13) PC computer; (14) Qing Chuan air-borne collection and recording system; (15) GPS reference station; (16) Ground instruments; (17) Ground computer; 18) Error data

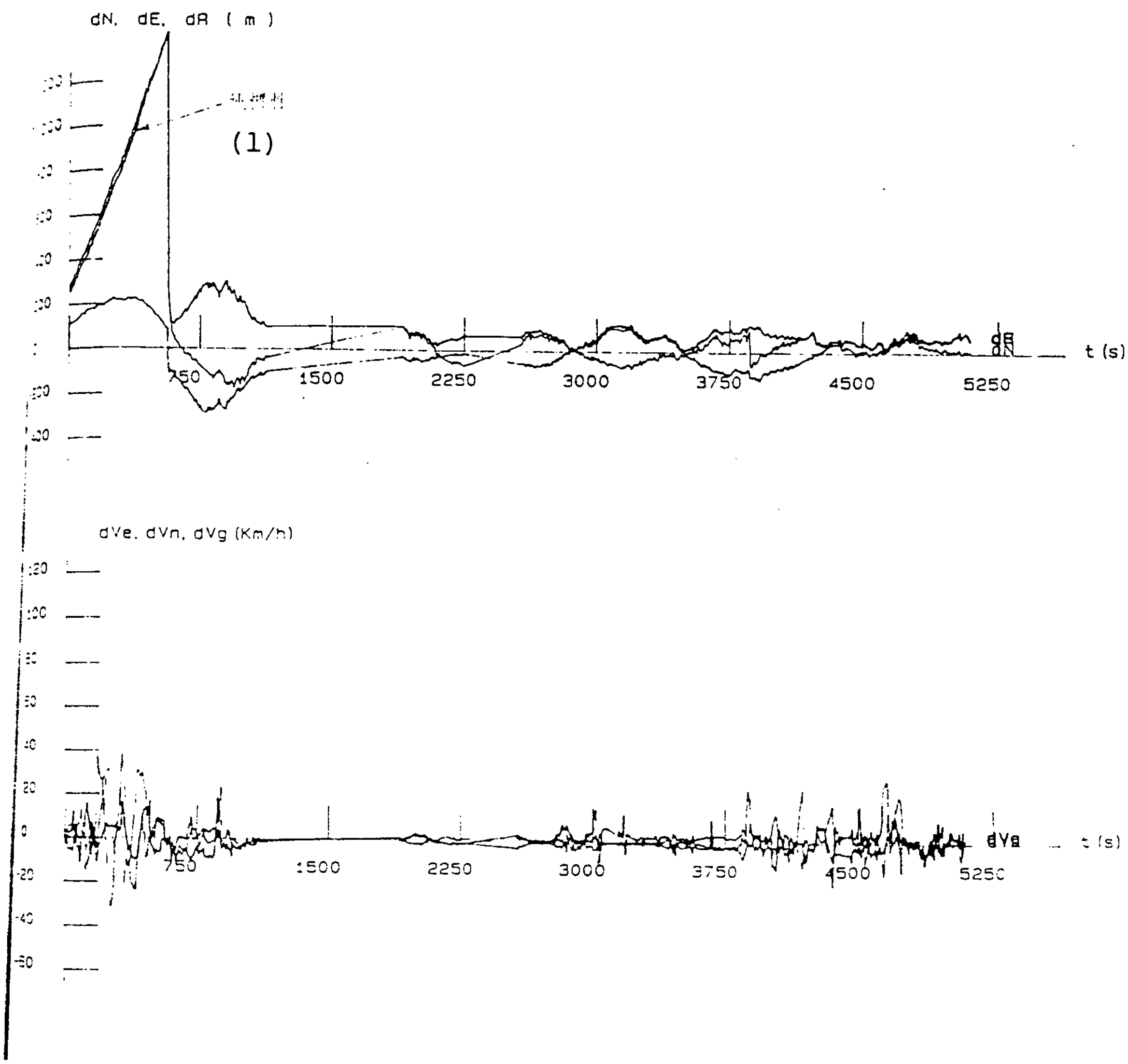

Fig. 4. Location and Velocity Error Curves of Platform Inertial Guidance/Satellite Navigation System Mounted in No. 4 Sortie

Key: (1) Purely inertial

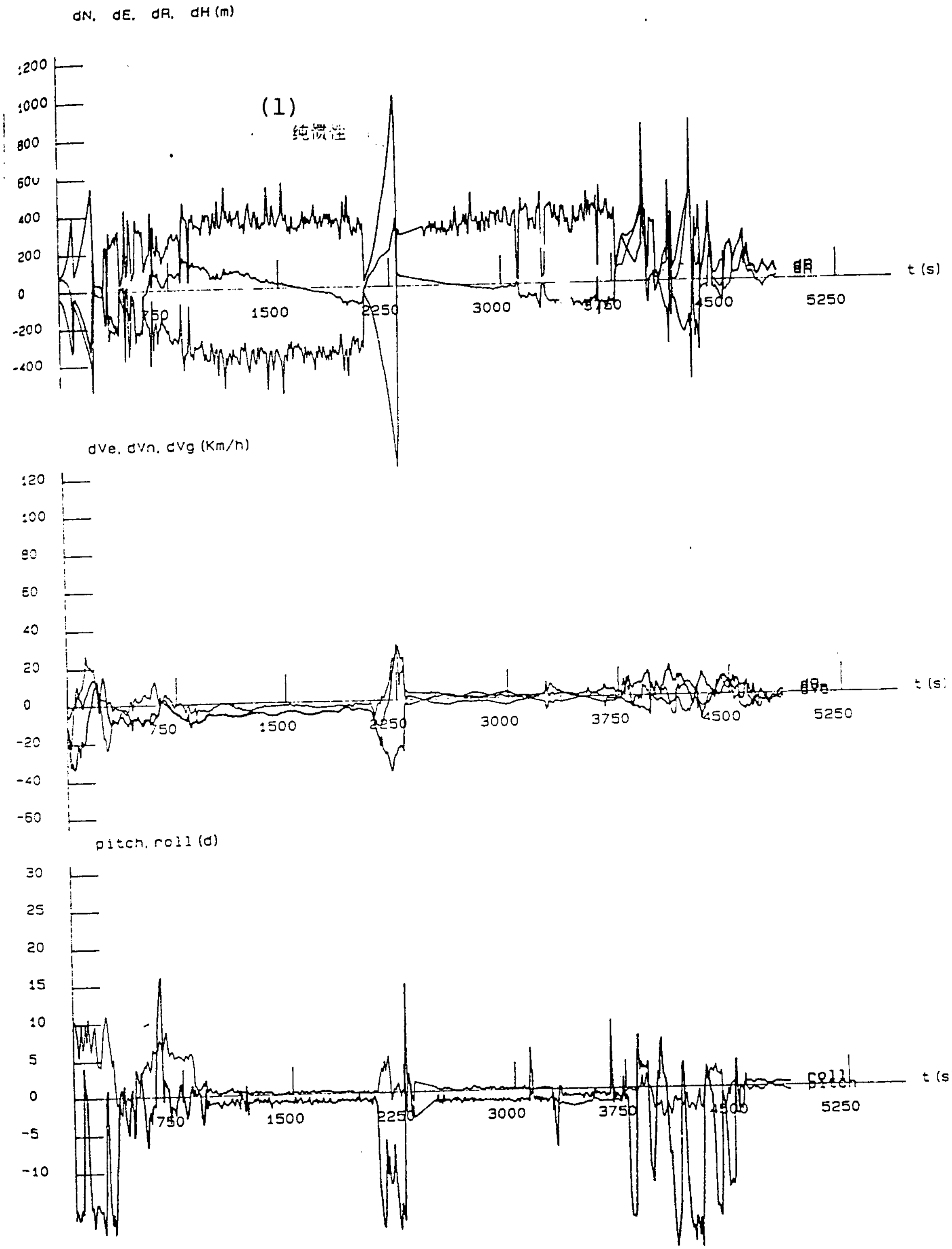

Fig. 5. Location and Velocity Error Curves of Strapdown Inertial Guidance/Satellite Navigation System Mounted in No. 7 Sortie

Key: (1) Purely inertial